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INPUT DATA FOR THE PREDICTION OF NOISE FROM TECHNICAL EQUIPMENT USING A HEAT PUMP

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ABSTRACT

An increasing use of renewable energy in heating technology can be observed in new building and refurbishment. Due to increasing costs there is a trend to build without a basement. In refurbishment often another storey is added in lightweight construction. For both situations there is the need to mount service equipment close to living and sleeping rooms in the same storey. This can be challenging particularly in timber constructions where low frequencies are of major interest. EN 12354-5 [1] describes methods for the prediction of noise from technical equipment. Considering structure-borne sound laboratory procedures to characterize sources in order to provide input data methods are given in EN 15657 [2]. Current research and development projects at Rosenheim Technical University of Applied Sciences face challenges with the characterization of the full data-set required for the prediction of heat pumps. This also involves acoustically optimized mounting conditions such as rubber mounts or similar. With any mounting situation there has to be a decision about the system boundary between source and receiver, or about the separate characterisation of the mountig support. This paper presents experiences in the application of the laboratory methods given in EN 15657. Airborne sound is not considered.

Keywords: *Structure-borne sound source characterisation, building acoustics*

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1. BACKGROUND: PREDICTION METHOD

EN 12354-5 describes methods for the estimation of sounds levels due to service equipment. In the latest revision prEN 12354-5 [1] major changes where made compared to the previous version from 2009. Airborne and structure-borne transmission are considered separately. For both transmission types input data for the source and the transmission across the building is required. The transmission paths in the building can be obtained either by means of calculations, e.g. for solid homogeneous constructions according to EN ISO 12354-2:2017-11 [3]. The transmission can be calculated for each path ij if the required input data is available. In addition it is possible to characterize the transmission as black box using measured global transmission functions [4]. This is appropriate and practical in particular for lightweight framed structures but can be applied to any construction type. It it also feasible to calculate the global transmission in advance and provide these data-sets for prediction. Considering structure-borne sound the main input quantity for the general case is the installed structure-borne sound power $L_{W\mathrm{s},i}$. It can be calculated, for example by using the blocked force, according to equation (1)

$$L_{W\mathrm{s},i} = 10 \cdot \lg \left(\frac{\mathrm{Re}\,(Y_\mathrm{R}) \cdot Y_0}{1 + \frac{|Y_\mathrm{R}|^2}{|Y_\mathrm{S}|^2}} \right) + L_{F\mathrm{b,eq}} \qquad (1)$$

where Y_R and Y_S are the magnitudes of the receiver and source mobility, $L_{F\mathrm{b,eq}}$ the level of the blocked force of the source and $Y_0 = 1\,\mathrm{m\,N/s}$.

2. LABORATORY MOCK-UP

The input data for prediction is determined according to EN 15657 [2]. This standard describes methods for direct

Figure 1: Heat pump with all required connections and piping for the operation mounted on a horizontal concrete reception plate.

and indirect measurement of the source properties. Figure 1 shows an example of the operational setup for a heat pump on the reception plate test rig for indirect measurement of the source characteristics according to EN 15657.

For the direct measurement at the contact points of the source, the building service equipment must ideally be operated in a free condition. This can practically realised using soft elastic mounts or rubber cords. However this can be challenging since often all the visible external housing components, except the mounting points, are not designed to carry static loads. Figure 2 shows an example of an elastic bearing of the heat pump. In this case simple wheel tubes are used in combination with a chipboard plate that distributes the load across the base plate of the heat pump in order to have free access to the feet. The natural frequency of this bearing was ≈ 6 Hz which is well below 31.5 Hz, the lowest one-third octave band of interest. A free-free condition is therefore assumed.

(a) Elastic bearing of the source

(b) Measure Y_S

Figure 2: Elastic bearing of the heat pump for the direct measurement of source quantities according to EN 15657.

For the operation of a heat pump, the heat dissipation with preferably controllable return flow temperatures, the supply and exhaust air, which may have to be conditioned, and the power supply must be provided. The monitoring of the operating conditions can often be carried out using the built-in sensors of the unit. In addition sensors for volume flow, pressure or temperature are useful to reproduce desired operating points precisely.

3. DETERMINATION OF THE SOURCE PARAMETERS

For the indirect measurement methods, the source must be operated on a reception plate. In this method, the active properties of the source are obtained from measurements of the surface velocity on the reception plate in combination with the total loss factor and the average mobility at the contact points between source and plate. This method offers advantages if vibration decoupling (isolation) measures are already included ex-factory. With the source being installed on a reception plate the elastic support exhibit the expected load of the source which is not the case in a free-free measurement. However, this indirect measurement with a heavy reception plate can only be applied in the case that the source mobility is high compared to the plate mobility.

Figure 3 shows the measured mobilities of a 10 cm reinforced concrete reception plate (heavy and stiff low mobility plate) and a typical timber-frame structure in comparison with the equivalent mobility of the heat pump. The source mobility Y_S is significantly higher compared to the mobility Y_R of the concrete plate and can therefore be considered as a force source. For this mobility ratio, $|Y_\mathrm{R}|^2/|Y_\mathrm{S}|^2$ from equation 1 can be neglected, and the blocked force levels determined by the indirect measurement method can be used directly for prediction. However, if the mobilities are in the same order of magnitude, this simplification is not possible.

For a complete source characterization, two of the three quantities free velocity L_vf, source mobility Y_S or blocked force L_Fb are required. Depending on the characteristics of the source, the methods that suit best can be

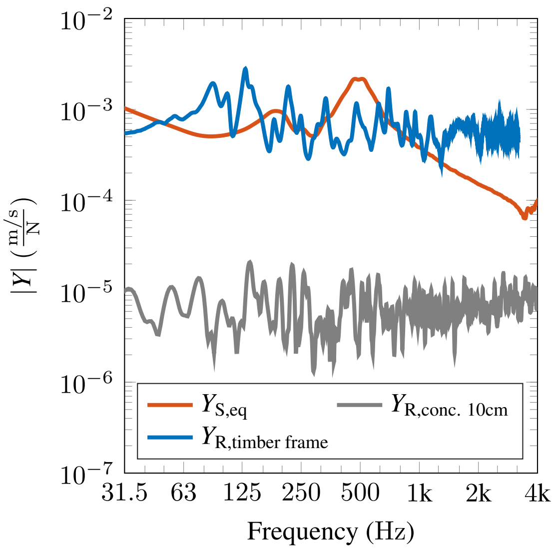


Figure 3: Magnitude of the point mobility from the heat pump and the two reception building components (10 cm concrete Plate and timber frame construction).

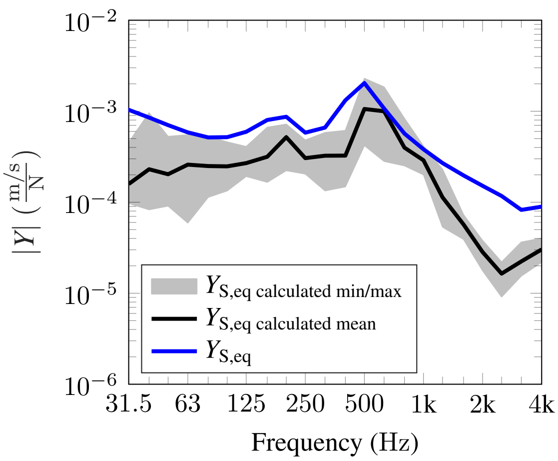


Figure 4: Comparison of the directly measured source mobility to the source mobility calculated according to equation 2.

chosen from EN 15657 and the missing parameters can be calculated from the known quantities. If for example, it is straightforward to determine the blocked force indirectly using a low mobility reception plate and the free velocity by direct measurement at the contact points, the required source mobility can be calculated from these two quantities according to equation (2). This was applied in this case study for a heat pump with four steel feet, i.e. stiff mounts for various operating conditions.

$$|Y_{\mathrm{S,eq,calculated}}| = \sqrt{10^{0.1(L_{v\mathrm{f,eq}} - L_{F\mathrm{b,eq}})} \cdot 10^{-6}} \qquad (2)$$

In addition, the source mobility was measured directly on the steel feet. Figure 4 shows a comparison between the mobility calculated from measured blocked force and free velocity and the directly measured mobility.

The shaded area shows the calculated mobility for the different operating conditions with the arithmetic mean value indicated by the black solid line. The frequency trend is picked up by the calculated mobility however it is shifted across the entire frequency range that was considered. The reason for this is not fully clear however a feasible explanation can be the bearing of the heat pump in the free velocity measurement (see figure 2a). Due to the mounting on the inner tubes and the additional load distribution plate, the free velocity at the contact points might have been reduced. Hence the calculated source mobility would also be underestimated.

4. BLOCKED FORCES LEVELS

When determining the sound power of heat pumps, the airborne sound measurements are carried out for well defined operating conditions. Such regulations are not available for structure-borne sound power characterization so far. Using the example of determined blocked force levels of a heat pump, which was investigated for different operating points, significant deviations in the force spectrum can be observed (Figure 5).

In the minimum operating conditions, i.e. minimum thermal power delivered, a significant excitation occurs only in the low frequency range. At the medium operating point, force level has the highest value for all operating conditions and is clearly shifted compared to the minimum operating condition. Additionally to the peak in the 100 Hz one-third octave band there are also force levels significantly above background up to 600 Hz. In the maximum operating point, the peak is in the 125 Hz one-

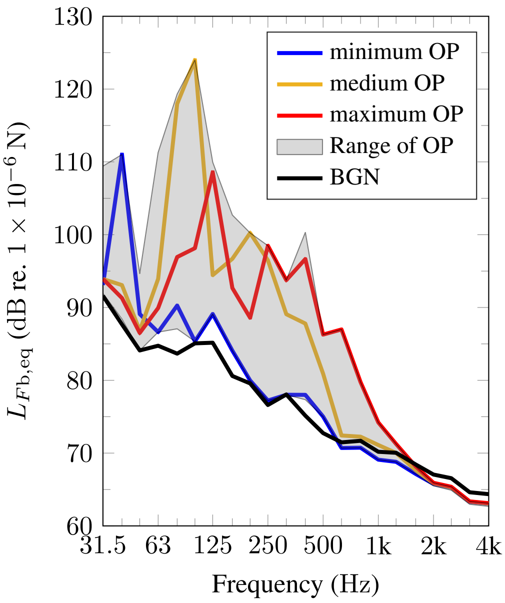


Figure 5: Measured blocked force levels of a heat pump at different operating points (BP) and the background noise level (BGN) without source operation.

third octave band and there is significant excitation up to 1 kHz.

With increasing thermal power delivery, the maximum blocked force increases in frequency. However, there is no correlation between the operating point and the absolute value of the maximum in the blocked force.

This shows that different operating points should be considered when determining the source input data for the prediction. Concerning a practical application it might be feasible to use the maximum of the investigated operating points for a conservative prediction.

5. DECOUPLING SOURCES

The measurement methods mentioned above can be used straight forward for building service equipment with rigid coupling. For the case of elastic mounts, the measurement methods might be limited, as the decoupling elements have load-dependent properties. Hence the direct measurement methods with a free source can not be applied. However, the indirect method (reception plate method) can still be applied reliably for sources with elastic feet or coupling conditions respectively.

Depending on the characteristics of the device, a significant reduction of the transmitted structure-borne sound into the structure can be achieved with elastic mounts. In prEN12354-5[1], the possibility of a source characterisation with rigid connection elements and an evaluation of the effectiveness of the decoupling (isolating) elements based on the mobility ratios of the source, the decoupling element and the receiver components is described. Alternatively, an independent structure-borne sound characterisation can be carried out for each combination of decoupling element and source. Based on this the effectiveness of the decoupling elements can be evaluated.

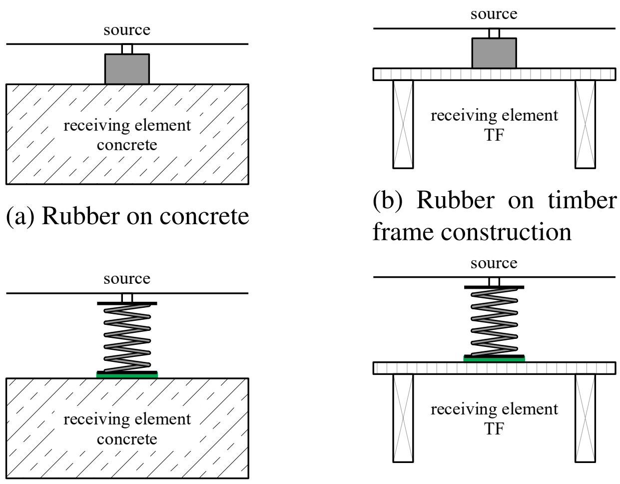
Another approach to asses the decoupling elements is to use the insertion loss D_e. This is defined according to equation (3) using the ratio, i.e. the level difference between velocity level measured on the receiving element with rigid coupling $L_{v,\mathrm{without}}$ (without decoupling element) and with a decoupling element $L_{v,\mathrm{with}}$ (see e.g. [5]). This method can be applied directly on a reception plate test-rig.

$$D_\mathrm{e} = L_{v,\mathrm{without}} - L_{v,\mathrm{with}} \tag{3}$$

In the context of source optimisations, investigations were carried out on the effectiveness of adjustable feet on different receiving elements. In this case study two adjustable feet (solid rubber and spring element with additional elastomer) were considered on two different receiving structures (concrete reception plate and timber-frame structure). Figure 6 shows four combinations of the adjustable feet considered and the two receiving structures. For these four combinations the insertion loss was measured. Figure 7 shows the results.

On the concrete slab (solid lines) the solid rubber feet (black solid line) shows an average insertion loss of ≈18 dB in frequency range from 31.5 Hz to 250 Hz. In comparison the spring element with elastomer provides a significantly higher insertion loss in this frequency range with an average of ≈29 dB, i.e. 11 dB higher than the rubber element. However above 250 Hz both elements perform similar.

On the timber-frame structure (dashed lines in figure 7), the insertion loss is significantly lower for both elements in particular for frequencies below 250 Hz. However, the spring elements with elastomer still perform better compared to the rubber elements at low frequencies. This highlights the need to take into account the properties of the receiving structure. The predicted performance of an elastic mount for a heavy and stiff receiver can not be applied to lightweight constructions.



(a) Rubber on concrete

(b) Rubber on timber frame construction

(c) Spring + elastomer on concrete

(d) Spring + elastomer on timber frame construction

Figure 6: Different posibilities of decoupled, adjustable feet and receiving structures to determine an insertion loss.

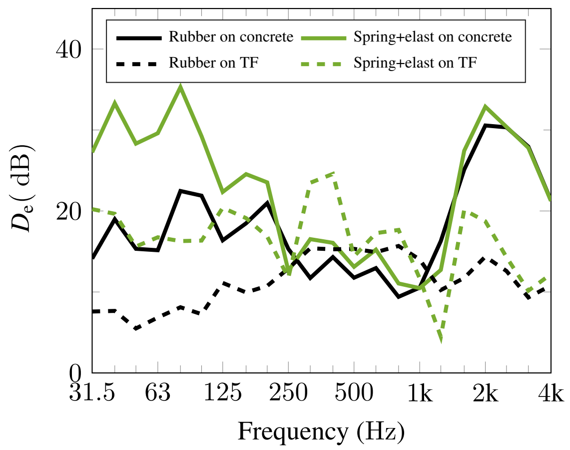


Figure 7: Level of insertion loss of two adjustable feet when the source is installed on a timber frame construction (TF) and a 10 cm reinforced concrete slab as receiving elements.

6. CONCLUSION AND OUTLOOK

For the prediction of noise from service equipment in buildings prEN 12354-5:2022 describes methods for airborne and structure-borne sound. However these methods require input data not only for the building but also for the sources, i.e. the technical equipment. It is currently not the aim to provide this data in the standards. Hence manufacturers need to provide this data-sets, which already is the case for airborne sound power. EN 15657 describes laboratory methods to determine these data-sets. Various methods are given including direct and indirect methods to determine the source quantities. Depending on the characteristics of the source the most suitable can be chosen. However there is still little experience with the practical application for the broad spectrum of technical equipment in buildings. And case studies such as the one presented in this paper show challenges in the application. Nevertheless the variety of methods given in EN 15657 allows already flexibility.

With regard to the structure-borne sound characterisation of sources, the selected operating points are decisive for the determined source properties. Depending on the operating point of the heat pump, there is significantly increasing structure-borne sound transmissions in individual one-third octave bands. A guideline for the operating points to be choosen is currently not available; in the future, it could be discussed which operating points should be selected for the source characterisation.

As the vibration-optimised installation will continue to gain relevance due to the increasing comfort demands, the separate evaluation of source, decoupling element and structure must be investigated in the future.

7. ACKNOWLEDGMENTS

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